A decision-making methodology for selecting trigeneration systems

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Abstract

The paper considers the selection of a cogeneration system as a multicriteria decision-making problem, which involves economical, technical, thermodynamic and environmental issues. Taking into account the preference information given by the Decision-Maker (DM) about the weight of each criterion, a ranked set of alternatives is obtained by solving a discrete optimization problem based on the Tchebycheff metric. The problem definition, the structure and the solution algorithms are described. The DM can identify the most favorable alternatives in a finite number of steps. The method is illustrated with the help of an example.

Keywords: Selecting cogeneration systems multicriteria analysis decision-making

1. Introduction

The utilization of cogeneration technology (CHP) can result in significant energy savings when the electricity, cooling and heat are used. In order to utilize their high economical and energy-saving potentials the system planning, especially the capacity of prime movers, is very important. The equipment sizing and the energy performance characteristics of cogeneration systems are strongly determined by system configuration and operational strategy. The following five cases (alternatives) were considered: sizing following the traditional thermal demand management (CHDM), sizing following the power demand management (CPDM), sizing by using the maximum power demand (CogP), sizing following the cooling and heating demand management (CCHP) and sizing following the power, cooling and heating demand management (CChM). More recently researchers are related to the optimization of plant lay out and to the real time optimization of operation strategy for existing plants [1,2,3]. Consequently, the purpose of this paper is to develop an optimal selecting method of determining the size of cogeneration plants taking into consideration operational strategies by using decision-making analysis and multi-criteria theory in a complex planning environment.

2. Selecting problem definition

The selecting problem for a cogeneration system can be very complex from several points of view: economical, technical, thermodynamic and environmental issues. In this problem a key factor is to decide where in the system the required energy conversion should take place and which should be the boundaries of the system. Additionally, each potential decision-maker might have different interests and different points of view concerning the selection criteria. The most important steps in defining and solving the selecting problem consists of identifying, structuring and providing a methodology which allows taking into consideration all the aspect that it involves. Figure 1 shows a summary of the cogeneration selecting problem.

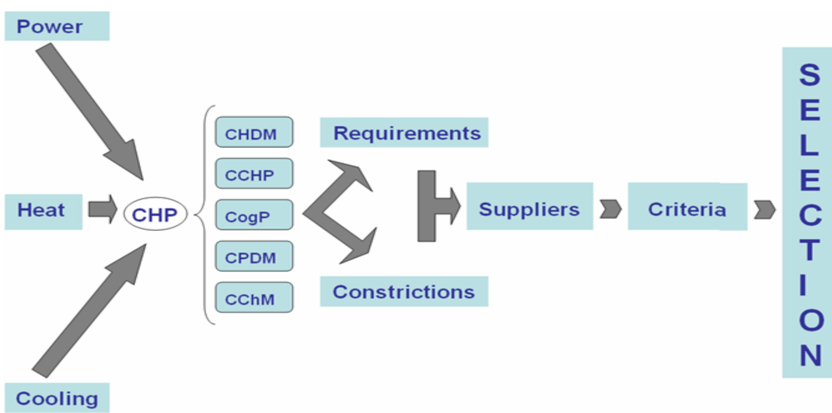

Fig. 1. Summary of the cogeneration selecting problem

At the demand side of the system, the energy meets a number of required services, such as heating, lighting, mechanical work, cooling etc., which should be covered totally or partially by means of a cogeneration plant. Firstly there are several methods available to size the system; but also constrictions and requirements should be considered. In addition a larger number of suppliers could be found. Moreover a great number of criteria can be defined to choose the end solution. Concluding, the problem can be formulated as follows: Decide the best size, investments and operation strategies in order to cover the energy service demands considering different technologies, configuration, management scenarios, operational strategies as well as constrictions and requirements.

3. Management scenarios and impact assessment or criteria

Two scenarios are considered, whether the exportation of power to the grid is allowed or not. In the second case, the power generated can only be used for internal requirements. A finite number of possibles solution “alternatives” can be defined, considering the limitation in the number of local energy resources, as well as, the limited number of available technical solutions for conversion, storage and transportation of these energy resources. Consequently we propose to separate the problem into a sizing and operation problem and an investment and a selecting problem. The whole problem can be seen as a multi-criteria problem that can be solved, for instance, using interactive and computational techniques. The main challenge then is to design a realistic process that allows successively and systematically to screen the set of non-dominated alternatives, so that the decision makers may identify the most favorable alternatives in a finite number of steps.

Following, a general discussion about different criteria that will be included in the cogeneration selecting problem is presented. A most frequently used economical criterion to compare different possibility of investment is the Net present value. Another economical criterion to a better understanding of the evaluation is to calculate the investment payback period. Many of the benefits of CHP come from the relatively high efficiency of it compared to other systems. The Fuel Energy Saving Ratio also called Percent of Fuel Saving, measures the extent of fuel savings directly in a CHP system [4], therefore constitutes a satisfactory criterion to evaluate cogeneration systems. Two major criteria for the environment assessment are considered: whether the geographical position of different technological solutions and the boundary of the system analyzed are taken into account. The amounts of CO_2 not sent to the atmosphere, as well as an

Environmental Cost–Benefit criterion to evaluate the local emissions impact of each alternative analyzed

4. General algorithm by using multi-criteria analysis

An algorithm of the proposed selecting framework is shown in figure 2. Since the decision makers at these stages are already involved, an interactive dialog will take place before the optimization routine generates a list of possible solutions.

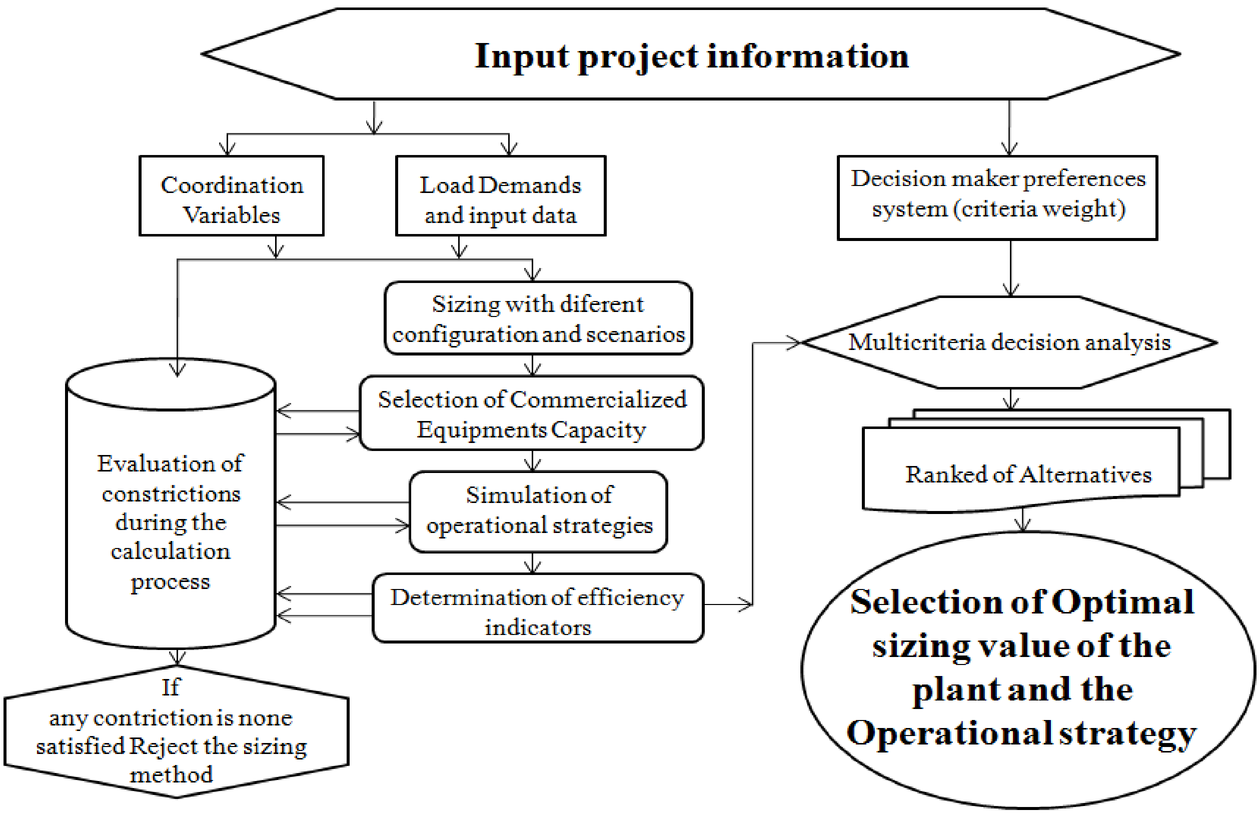

Fig. 2. Algorithm for selecting cogeneration systems by using multi-criteria analysis

The proposed approach is to create a tool which permit that different kinds of decision-makers, with different interests can use it in an equally efficient manner. The optimization process will be interactive so that the decision maker may identify the most favorable alternatives in a finite number of steps. Structuring the problem is primarily based on forming relationships between several kinds of variables, for instance: the input data, the coordination variable, the decision variables and the efficiency indicators [5]. The optimization process expresses the relationship between the design parameters and the overall system performance. It is expressed in terms of the utility function (U). This structure is assumed to be disposed to discrete optimization and, therefore, formulated in terms of a set of input system design parameters (a_n, u_k, d_r) and a set of output system performance measures ψ_m (efficiency indicators).

System design parameters (a_l, u_k, d_r) are those variables defined by designers as critical factors that impact the system performance and direct its actual behavior. Examples of such parameters include the *Coordination variables* (u_k): sizing methods, voltage and frequency, fuel, suppliers, dimensions (length, height, width), possibility to sell power to the network or not, etc. The *Decision variables* (a_l) consist of the decision-maker preference system, in other words, the definition of the weights or importance of each efficiency indicator. While the third kind of variable, the *Input data* (d_r), consist of the hourly energy demands of the installation as well as the usual thermodynamic parameters like temperature, enthalpy, equipment efficiencies, etc. The set of system performance variables (Ψ_m), on the other hand, represents the efficiency indicators or criteria on which improvement of systems are measured [5]. Maximizing or minimizing levels of such indicators is, therefore, translated into design and improvement objectives. Multi-criteria approach is the search for the problem's optimal solution, taking into account the multiple objectives that form it. This gives the problem a vector character. Consequently, considering evaluating efficiency indicators counted m and evaluating objects (alternatives) counted n, the original indicators values can be defined as a decision matrix $\Psi=(\Psi_{ij})_{mn}$.

$$\psi = \begin{bmatrix} \psi_{11}, \psi_{12} \cdots \psi_{1m} \\ \cdots\cdots\cdots\cdots\cdots\cdots\cdots \\ \psi_{n1}, \psi_{n2} \cdots \psi_{nm} \end{bmatrix} \tag{1}$$

Following, the efficiency indicators are changed in optimality criteria by means of the following expression.

$$Z_{ij} = \psi_{ij}^{\theta_j} \qquad\qquad \psi_{ij} > 0 \tag{2}$$

Where:

$$\theta_j = \begin{cases} 1 & \text{If minimum value of } \psi_j \text{ is required} \\ -1 & \text{If maximum value of } \psi_j \text{ is required} \end{cases} \tag{3}$$

The objective function of the optimal selecting problem is the minimization of the vector space function. The image function of this vector space can be seen as a utility function [5]. If an appropriate utility result of each possible solution is obtained, then the most interest plan of action is given for the alternative with the best expected utility.

$$Min\left\{ \left[Z_1(\psi_1) Z_2(\psi_2), \ldots, Z_m(\psi_m)\right] \right\} \tag{4}$$

Subject to: $g_f(d_r, u_k) \geq b_f$

The theory offers us several frameworks in order to obtain a better approximation of the reality, see Ref. [2,3,5-8]. One possible way is assuming that the decision makers always want to obtain the closest alternative to the ideal function. If the minimum value of each criterion is obtained without taking into account the consequence in other criteria, an ideal vector space can be defined. Consequently an ideal utility function can also be defined as show below equation.

$$U^{id} = U_{(Z_1^{id}, \ldots, Z_m^{id})} \tag{6}$$

The process consists of calculating the distance or metric between the utility function of each alternative and the ideal utility function. We use the weighted *Tchebycheff metric* (p=∞) based on the description in Ref. [5,6] . In order to measure the accomplishment of the fundamental objectives, attribute scales have been used.

$$V^{i}_{p,w} = \left[\sum_{j=1}^{m} \left(w'_j * \frac{\left| Z_j - Z_j^{id} \right|}{\left| Z_j^{mx} - Z_j^{id} \right|} \right)^{p} \right]^{1/p} \tag{7}$$

$$p = \infty \qquad \left\{ Z_j, Z_j^{mx}, Z_j^{id} \in R^{n} \right\}$$

Following we briefly introduce a sample of weight based on Entropy Method. It firstly appeared in thermodynamics, and was introduced into the information theory later by Shannon, see Ref.[7]. Nowadays, it has been widely used in engineering, economy, finance. etc.[3,7-9]. The information content of the normalized outcomes of the attribute can be measured by means of an entropy value. When the difference of the value among the evaluating objects on the same indicator is high, while the entropy is small, it illustrates that this indicator provides more useful information, and the weight of this indicator should be set correspondingly high [9]. The value of weight from this calculation not only contains the information of the individual indicator, but the relationship among evaluating alternatives . In the m indicators, n evaluating objects for the evaluation problem, the entropy of jth indicator have been defined for unreliability with discrete probability distribution (P_{ij}) [9]. Firstly the decision matrix can be normalized as follow:

$$P_{ij} = \frac{\psi_{ij}}{\sum_{i=1}^{n} \psi_{ij}} ; \forall ij \tag{8}$$

As have been presented in Refs. [3,9], defining $k = 1/Ln(n)$, from a set of P_{ij} the entropy can be seen as:

$$Ej = -k * \sum_{i=1}^{n} \left[P_{ij} * Ln\left(P_{ij}\right) \right] ; \forall j \tag{9}$$

Finally, the weight of entropy of *j*th indicator could be defined as:

$$w_j = \frac{1-Ej}{\sum_{j=1}^{m}\left[1-Ej\right]};\forall j \tag{10}$$

If decision-maker has a preference system as a relative importance for each criterion (λj), the weights for the Entropy method can be obtained as follow:

$$w'_j = \frac{\lambda_j * w_j}{\sum_{j=1}^{m}\left[\lambda_j * w_j\right]};\forall j \tag{11}$$

The ranking of the alternatives can at this moment be done based on the *Tchebycheff metric* calculated.

5. Application of the proposed methodology

The effectiveness of the proposed methodology is illustrated by a numerical example about a diesel engine cogeneration plant for a hotel in tropical conditions. In this hotel, steam is used for cooking and supplying domestic hot water, while an electric chiller is used to cover the cooling demand. The cumulative curves indicating the annual variations of load demands, as well as, the time-of-use rate for purchased electricity, heat and cooling for one day were available. We have only considered five alternatives where it is not a priority to sell power to the grid. It is assumed that one unit is installed and there exist only one supplier for all cogeneration technology in all cases. In Fig. 3, on the left, the blue bars display the net present value while the red line represent the pay back period. On one hand, if the net present value were used as the only criterion, the alternative 5 would probably be chosen as the best one. On the other hand the alternative 1 would probably be preferred as the best one, if the pay back period were used as the main criterion. This graphs, on the left, give a good demonstration of how decision makers analyzing the same problem which can have different preferences resulting in different decisions.

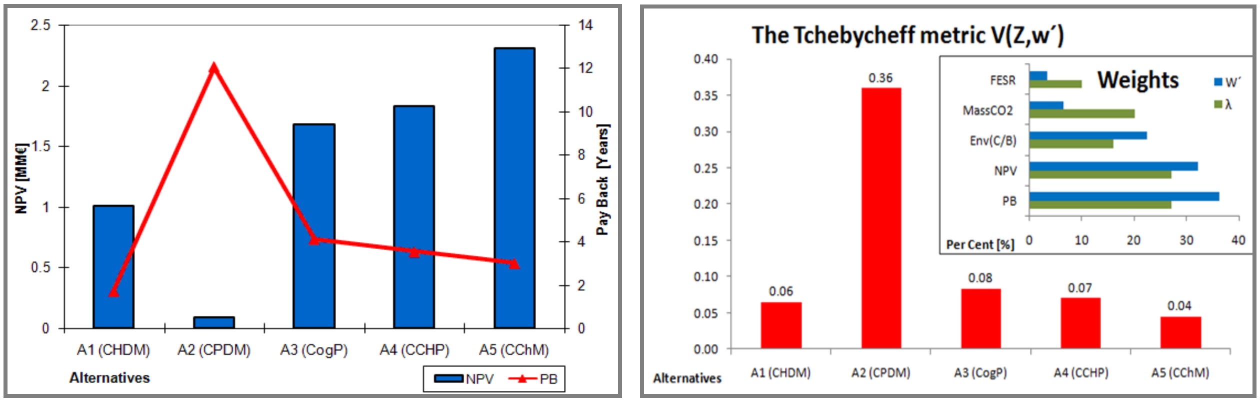

Fig. 3. Two efficiency indicators and the *Tchebycheff* metric for each alternative.

For the present analysis have been defined a probable preferences system from a given decision-maker. Having defined the preferences system, it is possible to calculate the *Tchebycheff* metric for each alternative as show figure 3, on the right. The alternative with the shortest value of this metric will be the best one, since it means that it is the closest one to the ideal function. In the current case of study the alternative 5 results in the most favorable solution. Once the best alternative has been defined, the equipment capacities can now be estimated on the basis of the selected strategy.

6. Conclusions

An optimal selecting methodology for cogeneration for buildings has been proposed on the basis of multi-criteria decision analysis. The characteristics of the selecting problem: the decision-makers preferences system, criteria, configuration, operational strategies, management scenarios as well as the entropy method to calculate the weights of criteria were discussed. We believe that the most important advantages of using multi-criteria decision methods consist in the structuring of information and the feasible combination of different criteria preference systems. For the studied case an optimal solution has been defined as well as a specific operational strategy. Through a numerical example concerning a cogeneration plant for a Hotel in tropical conditions, the effectiveness of the proposed methodology has been proved. By means of the characterization of the decision making process it becomes easier to certificate the reasoning behind decisions.

Nomenclature

Z	Optimality criterion		U^{id}	Ideal utility function
θ	Binary variable		w	Weight of a given criterion
Z^{id}	Ideal value of a given criterion		V_p^w	Weighted *Tchebycheff metric*
Z^{mx}	Maximum value of a given criterion		*i,j,k,f,r*	indices of variables
U	Utility function		*n, p*	dimensional space
b	Constant			

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